BASI DI DATI II – 2 modulo
Parte VI: XQuery

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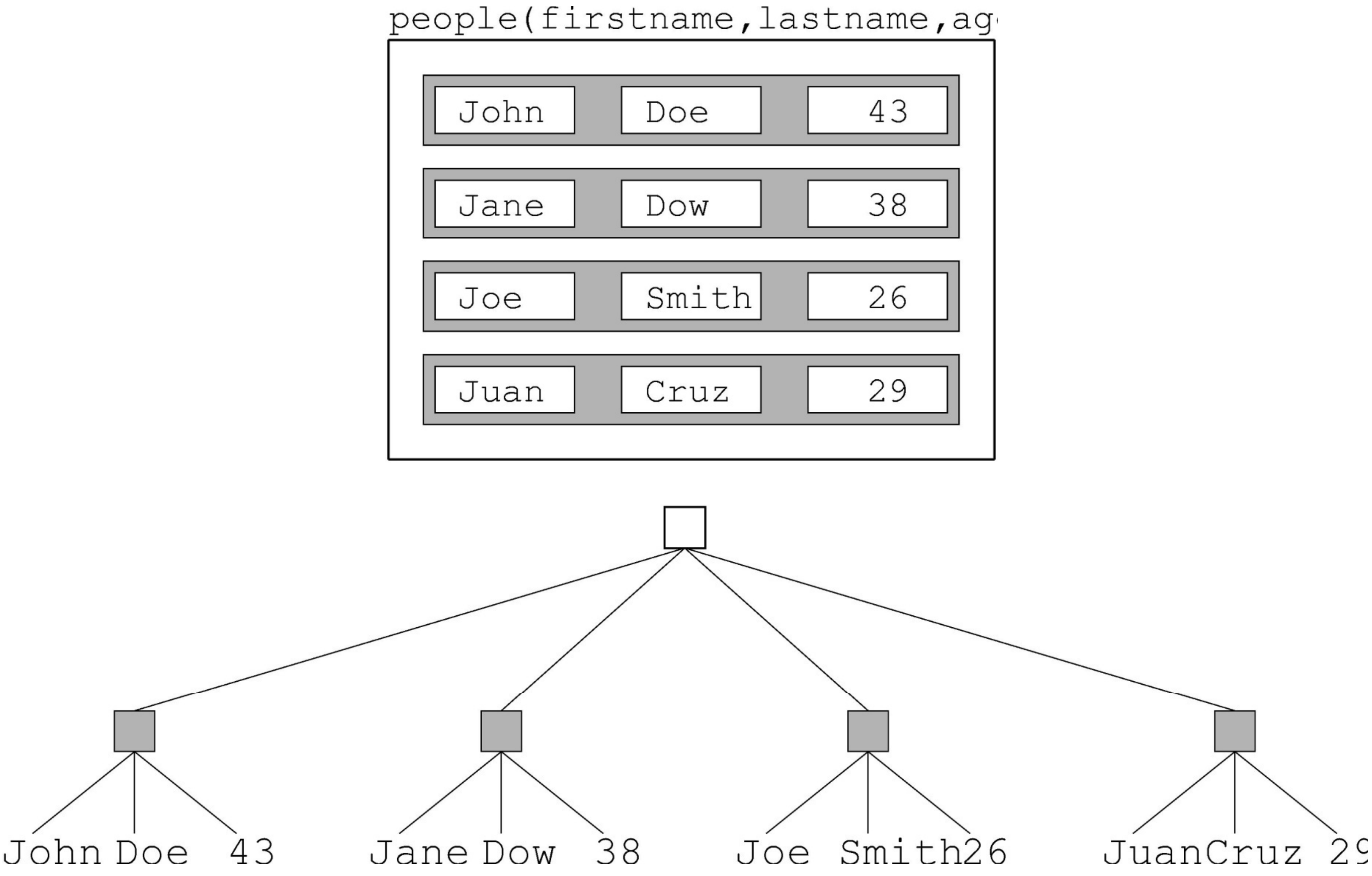
Outline

- How XML generalizes relational databases
- The XQuery language
- How XML may be supported in databases

XQuery 1.0

- XML documents naturally generalize database relations
- XQuery is the corresponding generalization of SQL

From Relations to Trees



people(firstname,lastname,ag

John	Doe	43
Jane	Dow	38
Joe	Smith	26
Juan	Cruz	29

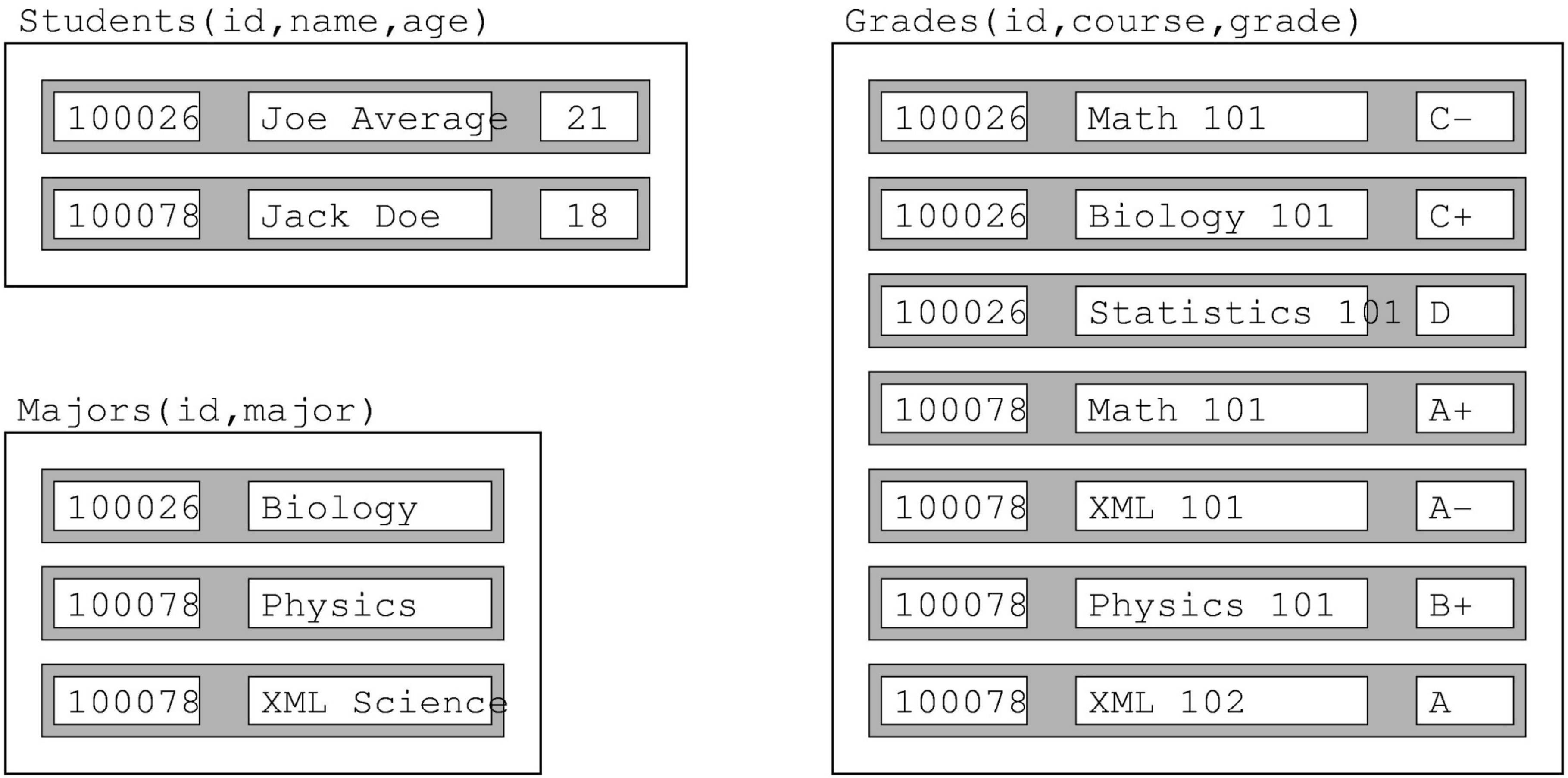
Only Some Trees are Relations

- They have height two
- The root has an unbounded number of children
- All nodes in the second layer (records) have a fixed number of child nodes (fields)

XML Trees Are Not Relations

- Not all XML trees satisfy the previous characterization
- XML trees are ordered, while both rows and columns of tables may be permuted without changing the meaning of the data

A Student Database



Students(id,name,age)

100026	Joe Average	21
100078	Jack Doe	18

Majors(id,major)

100026	Biology
100078	Physics
100078	XML Science

Grades(id,course,grade)

100026	Math 101	C−
100026	Biology 101	C+
100026	Statistics 101	D
100078	Math 101	A+
100078	XML 101	A−
100078	Physics 101	B+
100078	XML 102	A

A Natural Model in XML (1/2)

```
<students>
   <student id="100026">
      <name>Joe Average</name>
      <age>21</age>
      <major>Biology</major>
      <results>
        <result course="Math 101" grade="C-"/>
        <result course="Biology 101" grade="C+"/>
        <result course="Statistics 101" grade="D"/>
      </results>
   </student>
```

A More Natural Model in XML (2/2)

```
   <student id="100078">
      <name>Jack Doe</name>
      <age>18</age>
      <major>Physics</major>
      <major>XML Science</major>
      <results>
        <result course="Math 101" grade="A"/>
        <result course="XML 101" grade="A-"/>
        <result course="Physics 101" grade="B+"/>
        <result course="XML 102" grade="A"/>
      </results>
   </student>
</students>
```

Usage Scenarios for a DML

- Data-oriented
  - kinds of queries that we performed in the original relational model
- Document-Oriented
  - retrieve parts of documents, perform text-based searching, generate new documents as combinations of existing ones
- Hybrid
  - mine hybrid data, such as patient records

XQuery Design Requirements

- Must have at least one XML syntax and at least one human-readable syntax
- Must be declarative
- Must be namespace aware
- Must coordinate with XML Schema
- Must support simple and complex datatypes
- Must combine information from multiple documents
- Must be able to transform and create XML trees

Relationship to XPath

- XQuery 1.0 is a strict superset of XPath 2.0
- Every XPath 2.0 expression is directly an XQuery 1.0 expression (a query)
- The extra expressive power is the ability to
  - □ join information from different sources and
  - □ generate new XML fragments

Relationship to XSLT

- XQuery and XSLT are both domain-specific languages for combining and transforming XML data from multiple sources
- They are vastly different in design, partly for historical reasons
- XQuery is designed from scratch, XSLT is an intellectual descendant of CSS
- Generally:
  - XSLT: ideal for document-centric applications
  - XQuery: ideal for data-centric applications
- Technically: they may emulate each other

XQuery Prolog

- The prolog of XQuery expressions various parameters and settings, such as:

```
xquery version "1.0";
declare boundary-space preserve;
declare default element namespace URI;
declare default function namespace URI;
declare namespace prefix = URI;
import schema at URI;
```

Implicit Declarations

```
declare namespace xml =
  "http://www.w3.org/XML/1998/namespace";
declare namespace xs =
  "http://www.w3.org/2001/XMLSchema";
declare namespace xsi =
  "http://www.w3.org/2001/XMLSchema-instance";
declare namespace fn =
  "http://www.w3.org/2005/11/xpath-functions";
declare namespace xdt =
  "http://www.w3.org/2005/11/xpath-datatypes";
declare namespace local =
    "http://www.w3.org/2005/11/xquery-local-functions";
```

Context

- Like XPath expressions, XQuery expressions are evaluated relatively to a context
- The initial context node, position, and size are undefined
- The `fn:doc()` function is used to define the current context

Values in XQuery

- Same atomic values as XPath 2.0
- Also lots of primitive simple values using type constructors:

```
xs:string("XML is fun")
xs:boolean("true")
xs:decimal("3.1415")
xs:float("6.02214199E23")
xs:dateTime("1999-05-31T13:20:00-05:00")
xs:time("13:20:00-05:00")
xs:date("1999-05-31")
xs:gYearMonth("1999-05")
xs:gYear("1999")
xs:hexBinary("48656c6c6f0a")
xs:base64Binary("SGVsbG8K")
xs:anyURI("http://www.brics.dk/ixwt/")
xs:QName("rcp:recipe")
```

XQuery Expressions

- XPath expressions are also XQuery expressions
- XQuery expressions may compute new XML nodes
  - element, character data, comment, and processing instruction nodes
- Each node is created with a unique node identity
- Element constructors may be either direct or computed

Direct Constructors

- Uses the standard XML syntax
- The expression

  ```
  <foo><bar/>baz</foo>
  ```

  computes the given XML fragment
- Nodes are created with a unique identity:

  ```
  <foo/> is <foo/>
  ```

  evaluates to false

Namespaces in Constructors (1/2)

```
declare default element namespace "http://businesscard.org";
<card>
  <name>John Doe</name>
  <title>CEO, Widget Inc.</title>
  <email>john.doe@widget.com</email>
  <phone>(202) 555-1414</phone>
  <logo uri="widget.gif"/>
</card>
```

```
declare namespace b = "http://businesscard.org";
<b:card>
  <b:name>John Doe</b:name>
  <b:title>CEO, Widget Inc.</b:title>
  <b:email>john.doe@widget.com</b:email>
  <b:phone>(202) 555-1414</b:phone>
  <b:logo uri="widget.gif"/>
</b:card>
```

Namespaces in Constructors (2/2)

```
<card xmlns="http://businesscard.org">
  <name>John Doe</name>
  <title>CEO, Widget Inc.</title>
  <email>john.doe@widget.com</email>
  <phone>(202) 555-1414</phone>
  <logo uri="widget.gif"/>
</card>
```

Enclosed Expressions

```
{ exp }
```

- Denote computed contents
- May occur within an element
- Enclosed expression is evaluated and the resulting sequence is converted into XML contents as follows:
  - □ Sequences of atomic values are converted into a single character data obtained by converting each value to a string and separating these strings with single space characters
  - □ Each node is converted into a copy of the tree it roots, such that every node has a new, unique node identity

Example of XQuery evaluation

```
<students>
   <student id="100026">
      <name>Joe Average</name>
      <age>21</age>
      <major>Biology</major>
      <results>
        <result course="Math 101" grade="C-"/>
        <result course="Biology 101" grade="C+"/>
        <result course="Statistics 101" grade="D"/>
      </results>
   </student>
   <student id="100078">
      <name>Jack Doe</name>
      <age>18</age>
      <major>Physics</major>
      <major>XML Science</major>
      <results>
        <result course="Math 101" grade="A"/>
        <result course="XML 101" grade="A-"/>
        <result course="Physics 101" grade="B+"/>
        <result course="XML 102" grade="A"/>
      </results>
   </student>
</students>
```

```
declare boundary-space preserve;
<studentnames>
{fn:doc("student.xml")//student/name}
</studentnames>
```

```
<?xml version="1.0" encoding="UTF-8"?>
<studentnames>
    <name>Joe Average</name>
   <name>Jack Doe</name>
</studentnames>
```

Enclosed Expressions

```
<foo>1 2 3 4 5</foo>
<foo>{1, 2, 3, 4, 5}</foo>
<foo>{1, "2", 3, 4, 5}</foo>
<foo>{1 to 5}</foo>
<foo>1 {1+1} {" "} {"3"} {" "} {4 to 5}</foo>
```

```
<foo bar="1 2 3 4 5"/>
<foo bar="{1, 2, 3, 4, 5}"/>
<foo bar="1 {2 to 4} 5"/>
```

Explicit Constructors

```
<card xmlns="http://businesscard.org">
  <name>John Doe</name>
  <title>CEO, Widget Inc.</title>
  <email>john.doe@widget.com</email>
  <phone>(202) 555-1414</phone>
  <logo uri="widget.gif"/>
</card>
```

```
element card {
  namespace { "http://businesscard.org" },
  element name { text { "John Doe" } },
  element title { text { "CEO, Widget Inc." } } ,
  element email { text { "john.doe@widget.com" } },
  element phone { text { "(202) 555-1414" } },
  element logo {
    attribute uri { "widget.gif" }
  }
}
```

Computed Element and Attribute Names

```
element { "card" } {
  namespace { "http://businesscard.org" },
  element { "name" } { text { "John Doe" } },
  element { "title" } { text { "CEO, Widget Inc." } },
  element { "email" } { text { "john.doe@widget.com" } },
  element { "phone" } { text { "(202) 555-1414" } },
  element { "logo" } {
    attribute { "uri" } { "widget.gif" }
  }
}
```

Biliingual Business Cards

```
element { if ($lang=”Italian") then ”biglietto" else "card" }
    { namespace { "http://businesscard.org" },
  element { if ($lang="Italian") then ”nome" else "name" }
    { text { "John Doe" } },
  element { if ($lang="Italian") then ”titolo" else "title" }
    { text { "CEO, Widget Inc." } },
  element { "email" }
    { text { "john.doe@widget.inc" } },
  element { if ($lang="Italian") then "telefono" else "phone"}
    { text { "(202) 456-1414" } },
  element { "logo" } {
    attribute { "uri" } { "widget.gif" }
  }
}
```

FLWOR Expressions

- Used for general queries:

```
<doubles>
  { for $s in fn:doc("students.xml")//student
    let $m := $s/major
    where fn:count($m) ge 2
    order by $s/@id
    return <double>
             { $s/name/text() }
           </double>
  }
</doubles>
```

Evaluation result

```
<students>
   <student id="100026">
      <name>Joe Average</name>
      <age>21</age>
      <major>Biology</major>
      <results>
        <result course="Math 101" grade="C-"/>
        <result course="Biology 101" grade="C+"/>
        <result course="Statistics 101" grade="D"/>
      </results>
   </student>
   <student id="100078">
      <name>Jack Doe</name>
      <age>18</age>
      <major>Physics</major>
      <major>XML Science</major>
      <results>
        <result course="Math 101" grade="A"/>
        <result course="XML 101" grade="A-"/>
        <result course="Physics 101" grade="B+"/>
        <result course="XML 102" grade="A"/>
      </results>
   </student>
</students>
```

```
<?xml version="1.0" encoding="UTF-8"?>
<doubles>
    <double>Jack Doe</double>
</doubles>
```

The Difference Between For and Let (1/2)

```
for $x in (1, 2, 3, 4)
let $y := ("a", "b", "c")
return ($x, $y)
```

```
1, a, b, c, 2, a, b, c, 3, a, b, c, 4, a, b, c
```

```
let $x := (1, 2, 3, 4)
for $y in ("a", "b", "c")
return ($x, $y)
```

```
1, 2, 3, 4, a, 1, 2, 3, 4, b, 1, 2, 3, 4, c
```

The Difference Between For and Let (2/2)

```
for $x in (1, 2, 3, 4)
for $y in ("a", "b", "c")
return ($x, $y)
```

```
1, a, 1, b, 1, c, 2, a, 2, b, 2, c,
3, a, 3, b, 3, c, 4, a, 4, b, 4, c
```

```
let $x := (1, 2, 3, 4)
let $y := ("a", "b", "c")
return ($x, $y)
```

```
1, 2, 3, 4, a, b, c
```

Computing Joins

- What recipes can we (sort of) make?

```
<fridge>
  <stuff>eggs</stuff>
  <stuff>olive oil</stuff>
  <stuff>ketchup</stuff>
  <stuff>unrecognizable moldy thing</stuff>
</fridge>
```

```
declare namespace rcp = "http://www.uniroma3.it/recipes";
for $s in fn:doc("fridge.xml")//stuff
for $r in fn:doc("recipes.xml")//rcp:recipe
for $i in $r//rcp:ingredient/@name
Where $s/text()=$i
return fn:distinct-values($r/rcp:title/text())
```

```
tuple generate: ($s, $r, $i)
```

Nested queries

```
declare namespace rcp = "http://www.brics.dk/ixwt/recipes";
<ingredients>
 { for $i in distinct-values (
       fn:doc("recipes.xml")//rcp:ingredient/@name
    )
    return
       <ingredient name="{$i}">
          { for $r in fn:doc("recipes.xml")//rcp:recipe
               where $r//rcp:ingredient[@name=$i]
               return <title>{$r/rcp:title/text()}</title>
          }
       </ingredient>
  }
</ingredients>
```

The Output

```
<?xml version="1.0" encoding="UTF-8"?>
<ingredients>
   <ingredient name="beef cube steak">
      <title>Beef Parmesan with Garlic Angel Pasta</title>
   </ingredient>
   ...
   <ingredient name="filling">
      <title>Ricotta Pie</title>
      <title>Cailles en Sarcophages</title>
   </ingredient>
   ...
</ingredients>
```

Sorting the Results

```
declare namespace rcp = "http://www.uniroma3.it/recipes";
<ingredients>
  { for $i in distinct-values(
       fn:doc("recipes.xml")//rcp:ingredient/@name
    )
    order by $i
    return
       <ingredient name="{$i}">
          { for $r in fn:doc("recipes.xml")//rcp:recipe
            where $r//rcp:ingredient[@name=$i]
            order by $r/rcp:title/text()
            return <title>{$r/rcp:title/text()}</title>
          }
       </ingredient>
  }
</ingredients>
```

The Output

```
<?xml version="1.0" encoding="UTF-8"?>
<ingredients>
 <ingredient name="alchermes liquor">
      <title>Zuppa Inglese</title>
   </ingredient>
   <ingredient name="angel hair pasta">
      <title>Beef Parmesan with Garlic Angel Pasta</title>
   </ingredient>
   <ingredient name="baked chicken">
      <title>Cailles en Sarcophages</title>
   </ingredient>
   ...
</ingredients>
```

A More Complicated Sorting

```
for $s in document("students.xml")//student
order by
  fn:count($s/results/result[fn:contains(@grade,"A")]) descending,
  fn:count($s/major) descending,
  xs:integer($s/age/text()) ascending
return $s/name/text()
```

Using Functions

```
declare function local:grade($g) {
  if ($g="A") then 4.0 else if ($g="A-") then 3.7
  else if ($g="B+") then 3.3 else if ($g="B")  then 3.0
  else if ($g="B-") then 2.7 else if ($g="C+") then 2.3
  else if ($g="C")   then 2.0 else if ($g="C-") then 1.7
  else if ($g="D+") then 1.3 else if ($g="D")  then 1.0
  else if ($g="D-") then 0.7 else 0
};

declare function local:gpa($s) {
  fn:avg(for $g in $s/results/result/@grade return local:grade($g))
};

<gpas>
  { for $s in fn:doc("students.xml")//student
    return <gpa id="{$s/@id}" gpa="{local:gpa($s)}"/> }
</gpas>
```

A Height Function

```
declare function local:height($x) {
  if (fn:empty($x/*)) then 1
  else fn:max(for $y in $x/* return local:height($y))+1
};
```

Sequence Types

```
2 instance of xs:integer
2 instance of item()
2 instance of xs:integer?
() instance of empty()
() instance of xs:integer*
(1,2,3,4) instance of xs:integer*
(1,2,3,4) instance of xs:integer+
<foo/> instance of item()
<foo/> instance of node()
<foo/> instance of element()
<foo/> instance of element(foo)
<foo bar="baz"/> instance of element(foo)
<foo bar="baz"/>/@bar instance of attribute()
<foo bar="baz"/>/@bar instance of attribute(bar)
fn:doc("recipes.xml")//rcp:ingredient instance of element()+
fn:doc("recipes.xml")//rcp:ingredient
   instance of element(rcp:ingredient)+
```

An Untyped Function

```
declare function local:grade($g) {
  if ($g="A") then 4.0 else if ($g="A-") then 3.7
  else if ($g="B+") then 3.3 else if ($g="B")  then 3.0
  else if ($g="B-") then 2.7 else if ($g="C+") then 2.3
  else if ($g="C")  then 2.0 else if ($g="C-") then 1.7
  else if ($g="D+") then 1.3 else if ($g="D")  then 1.0
  else if ($g="D-") then 0.7 else 0
};
```

The Default Typing of a Function

```
declare function local:grade($g as item()*) as item()* {
  if ($g="A") then 4.0 else if ($g="A-") then 3.7
  else if ($g="B+") then 3.3 else if ($g="B")  then 3.0
  else if ($g="B-") then 2.7 else if ($g="C+") then 2.3
  else if ($g="C")  then 2.0 else if ($g="C-") then 1.7
  else if ($g="D+") then 1.3 else if ($g="D")  then 1.0
  else if ($g="D-") then 0.7 else 0
};
```

Precisely Typed Functions

```
declare function local:grade($g as xs:string) as xs:decimal {
  if ($g="A") then 4.0 else if ($g="A-") then 3.7
  else if ($g="B+") then 3.3 else if ($g="B")  then 3.0
  else if ($g="B-") then 2.7 else if ($g="C+") then 2.3
  else if ($g="C")  then 2.0 else if ($g="C-") then 1.7
  else if ($g="D+") then 1.3 else if ($g="D")  then 1.0
  else if ($g="D-") then 0.7 else 0
};
```

```
declare function local:grades($s as element(students))
    as attribute(grade)* {
       $s/student/results/result/@grade
    };
```

Runtime Type Checks

- Type annotations are checked during runtime
- A runtime type error occurs when:
  - □ an actual argument value does not match the declared type
  - □ a function result value does not match the declared type
  - □ a valued assigned to a variable does not match the declared type

Built-In Functions Have Signatures

```
fn:contains($x as xs:string?, $y as xs:string?)
   as xs:boolean
```

```
op:union($x as node()*, $y as node()*) as node()*
```

XQueryX

```
for $t in fn:doc("recipes.xml")/rcp:collection/rcp:recipe/rcp:title
return $t
```

```
<xqx:module
     xmlns:xqx="http://www.w3.org/2003/12/XQueryX"
     xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
     xsi:schemaLocation="http://www.w3
xqueryx.xsd">
  <xqx:mainModule>
```

```
<xqx:stepExpr>
  <xqx:xpathAxis>child</xqx:xpathAxis>
  <xqx:elementTest>
   xqx:nodeName>
     <xqx:QName>rcp:collection</xqx:QName>
   /xqx:nodeName>
   qx:elementTest>
   :stepExpr>
   stepExpr>
   x:xpathAxis>child</xqx:xpathAxis>
   x:elementTest>
   xqx:nodeName>
     <xqx:QName>rcp:recipe</xqx:QName>
   /xqx:nodeName>
   qx:elementTest>
   :stepExpr>
   stepExpr>
   x:xpathAxis>child</xqx:xpathAxis>
```

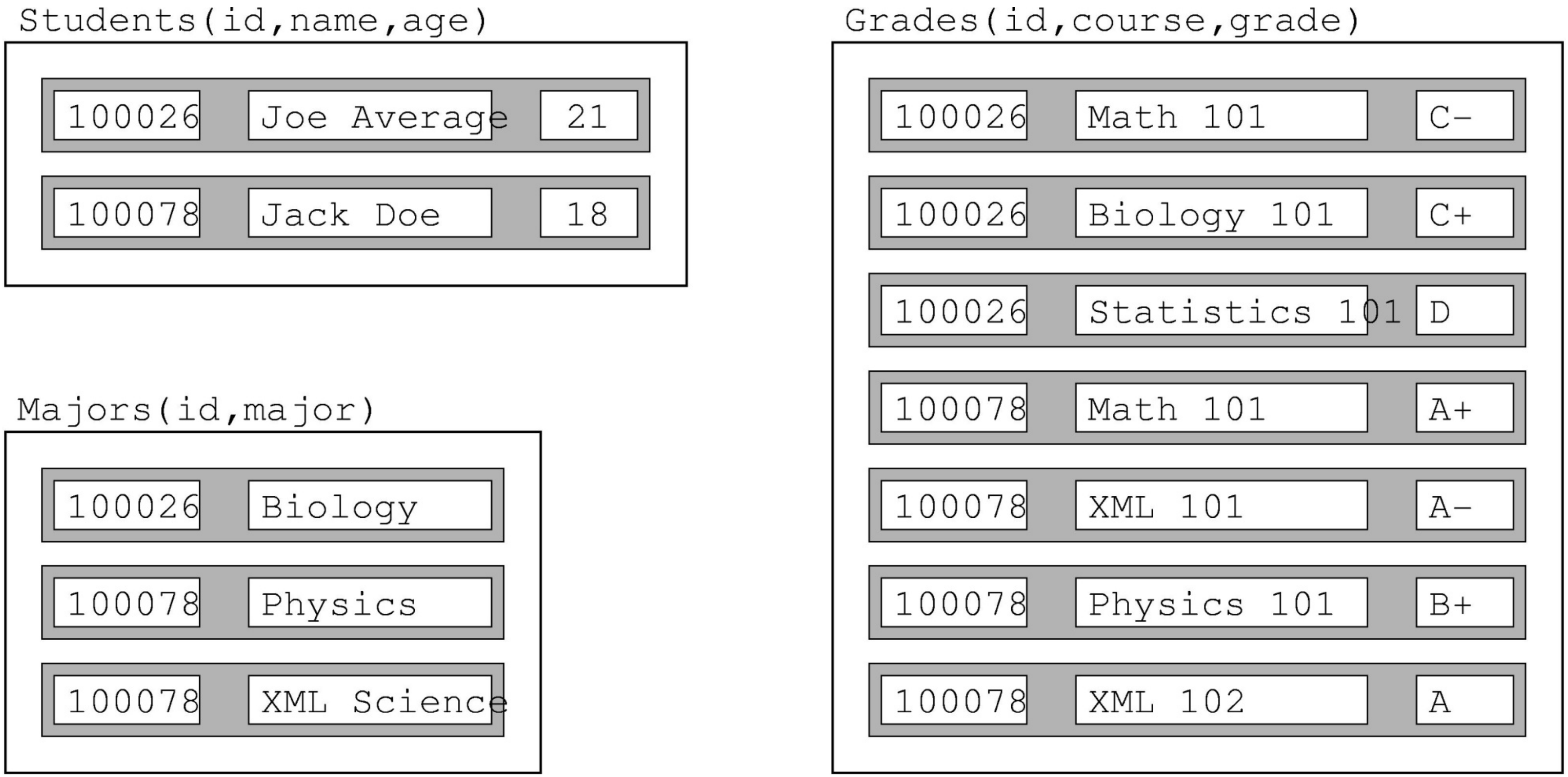
```
                          xqx:nodeName>
                           <xqx:QName>rcp:title</xqx:QName>
                         </xqx:nodeName>
                       </xqx:elementTest>
                     </xqx:stepExpr>
                   </xqx:expr>
                 </xqx:forExpr>
               </xqx:forClauseItem>
             </xqx:forClause>
             <xqx:returnClause>
               <xqx:expr xsi:type="xqx:variable">
                 <xqx:name>t</xqx:name>
               </xqx:expr>
             </xqx:returnClause>
           </xqx:expr>
         </xqx:elementContent>
       </xqx:expr>
     </xqx:queryBody>
   </xqx:mainModule>
</xqx:module>
```

XML Databases

- How can XML and databases be merged?

- Several different approaches:
  - XML-Enabled DBMS
    - extract XML views of relations
    - use XQuery or SQL/XML to generate XML
    - shred XML into relational databases
  - Native XML DBMS
    - store and manage XML in a native format

The Student Database Again



Students(id,name,age)

100026	Joe Average	21
100078	Jack Doe	18

Majors(id,major)

100026	Biology
100078	Physics
100078	XML Science

Grades(id,course,grade)

100026	Math 101	C−
100026	Biology 101	C+
100026	Statistics 101	D
100078	Math 101	A+
100078	XML 101	A−
100078	Physics 101	B+
100078	XML 102	A

Automatic XML Views (1/2)

```
<Students>
  <record id="100026" name="Joe Average" age="21"/>
  <record id="100078" name="Jack Doe" age="18"/>
</Students>
```

```
<Students>
  <record>
    <id>100026</id>
    <name>Joe Average</name>
    <age>21</age>
  </record>
  <record>
    <id>100078</id>
    <name>Jack Doe</name>
    <age>18</age>
  </record>
</Students>
```

Programmable Views in SQL/XML

```
xmlelement(name, "Students",
  select xmlelement(name,
                    "record",
                    xmlattributes(s.id, s.name, s.age))
  from Students as s
)
```

```
xmlelement(name, "Students",
  select xmlelement(name,
                    "record",
                    xmlforest(s.id, s.name, s.age))
  from Students as s
)
```

XML Shredding

- Each element type is represented by a relation
- Each element node is assigned a unique key in document order
- Each element node contains the key of its parent
- The possible attributes are represented as fields, where absent attributes have the null value
- Contents consisting of a single character data node is inlined as a field

From XQuery to SQL

- Any XML document can be faithfully represented
- This takes advantage of the existing database implementation
- Queries must now be phrased in ordinary SQL rather than XQuery
- But an automatic translation is possible

```
//rcp:ingredient[@name="butter"]/@amount
```

```
select ingredient.amount
from ingredient
where ingredient.name="butter"
```

Alternative approach

- XML data is directly stored in a special nested format
- No standards: the format is proprietary
- XSLT and XQuery are used to manage the database

Full-text searching

```
declare namespace rcp = "http://www.uniroma3.it/recipes";
for $r in fn:doc(Recipes.xml”)//rcp:recipe
where $r//rcp:preparation ftcontains
   (“chop” with stemming
           with default tesaurus ) &&
   (“onion” || “onions”)
   distance at most 5 words
   case insensitive
return $r
```

Summary

- XML trees generalize relational tables
- XQuery similarly generalizes SQL

- XQuery and XSLT have roughly the same expressive power
- But they are suited for different application domains: data-centric vs. document-centric

Essential Online Resources

- http://www.w3.org/TR/xquery/
- http://www.galaxquery.org/
- http://www.w3.org/XML/Query/